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Original Paper

Assessment of Urban Heat Island and Spatiotemporal Landscape Transformation in Three Cities of Sindh, Pakistan

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Abstract

Urban Heat Island is considered one of the main causes of urbanization. It impacts the overall livability of a city. It is mainly due to the biophysical changes of the land surface due to urbanization. This study is based on three cities of Sindh namely: Hyderabad, Sukkur and Larkana. To study the UHI effects, a Land Surface Temperature algorithm is used. Land use land cover changes are identified by using Maximum likelihood classification. This study reveals that there is a major change in urban development in Hyderabad and Sukkur that is (82 to 97) Km^2 and (18 to 25.7) Km^2, respectively. While, in Larkana, minimal urban development is observed (33 to 34.6) Km^2. Similarly, massive changes in vegetation are also observed in Sukkur and Larkana from 1990 to 2020 that are (90 to 161) Km^2 and (82 to 331) Km^2, respectively. Increase in vegetation is majorly due to the agricultural activities mainly occurring in different seasons. This study confirms that the LST has a strong negative correlation with NDVI because with increasing vegetation the LST is reduced. The findings also reveal that the major source of increased surface temperature is not only urban areas but the bare lands. The study finds that the skin temperature of the ground drops at least 3-5 degrees in the areas having a water body or any vegetation. This research highlights the importance of the inclusion of green strategies in better and effective urban planning to maintain a healthy urban environment.

Keywords: Land use land cover changes, Land surface temperature, NDVI, Sindh

Introduction

Urbanization is an unavoidable process due to amplified economic progress and unprecedented population growth [1]. According to [2] by the next two decades, at least 68% of the total world population will be living in urban areas. Which is growing three times faster than their rural correspondents [3]. A similar trend is being observed in Pakistan, from 39.7% of the urban population is growing yearly by 2.77% [4]. This rapid expansion of urban growth may cause severe environmental concerns [5]. One of the major impacts of urbanization is the Urban Heat Island (UHI) effect due to an increase in the urban temperature. It also affects the energy balance of land use land cover (LULC) due to the conversion of land from vegetation to concrete based infrastructures [6]–[8]. These changes in land covers may affect the average thermal capacity, other similar environmental aspects such as moisture content and albedo effect, etc [9], [10]. Hence, the urban temperature may rise by 2 to 6 degrees Celsius in summers. While this rise in the temperature may rise many degrees in winters [11]. UHI may cause adverse changes including the impact on local climate in the form of extreme heatwaves and thermal discomfort [12], [13]. This climate variability may disrupt agriculture and other socioeconomic activities [14], [15]. Urban Heat Island is normally classified into two types: Surface and Atmospheric UHIs. The Surface UHI solely depends upon Land Surface Temperature (LST). It can be measured by modern remote sensing methods [16], [17]. Another one is based on air temperatures and further classifies into canopy layer UHI and Boundary Layer UHI [18]–[21].

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With time, Remote Sensing is now getting more and more common in the study of urban morphology [22]–[24]. LST can be retrieved from thermal infrared sensors that calculate brightness temperature from atmospheric radiance [25]. Many studies have suggested that the LST remains within a close relationship with the urban morphology and the ambient air temperature [18][24], [26]–[31].

These three cities were selected because of the rapid increase in the rate of urbanization and population increase. These cities are of the biggest cities of Sindh after Karachi city.

This study focuses on the remote sensing approach to study the UHI by working on the LST algorithm. The purpose of this paper is to find out the urban heat in three major cities of Sindh, Pakistan. Therefore, the main objectives are (1) to assess the pattern of LULC changes and its impact on urban temperature during the period of 1990 to 2020, (2) to analyze the relationship between changes in the urban landscape and LST (3) and to study the phenomenon of UHI in three big cities of Sindh province.

Materials and Methods

Case study

This study is based on the three major cities of Sindh province of Pakistan namely, Hyderabad, Larkana and Sukkur as shown in figure 1. Sindh is the second largest province of Pakistan by population. It is located in the Southeast of the country. These cities were selected for this study because of rapid urban development that may help study the UHI effect. These cities also have importance due to their agricultural activities. Hyderabad city is the second-largest city of Sindh after Karachi and situated at latitude of 25° 22′ 45″ North and longitude of 68° 22′ 06″ East [32], [33]. The city has an area of 292 Km^2 and provides residence to 1.73 million people as per the population census of 2017 [34]. Sukkur is the third-largest city of Sindh. It is located between 27° 42' 0" North and 68° 52' 0" East. It has a population of 0.5 million inhabitants [35]. Similarly, Larkana is positioned in the Northwestern part of Sindh Province at longitude 68°12'51" East and at latitude 27°33'18" North. It has a population of 0.49 million, according to the population census of 2017.

Acquisition of data

The satellite imageries of the Landsat 5 TM, and 8 OLI/TIRS for the years 1990 and 2020 respectively, were used as the primary dataset and downloaded from earth explorer- USGS. The data taken was of the summer time of March and April, see table 1. Composite images were required before any pre-processing steps [36].

Extraction of Indices

Two different indices were calculated from the Landsat imageries for the years 1990 and 2020. The normalized difference vegetation index (NDVI) is used to separate the vegetation in the images. [37]. While, the urban features are indicated by normalized difference built-up index (NDBI) [38]. From equation 1 and 2, R, NIR and SWIR, represents red, near-infrared and shortwave infrared bands of Landsat satellite imagery [39], [40].

NDVI = (NIR – R / NIR + R) ……. Eq 01

NDBI = (SWIR – NIR / SWIR + NIR) –Eq 02

LULC classification

Land use Land cover classification was done by using maximum likelihood classifier tool in ArcMap 10.7. The selected years were 1990 and 2020 to find out the thirty years change. The images were classified into five different classes namely, Bare land, Built-up Land, Water (Rivers, canals, ponds, fields), Agriculture and nonagricultural green spaces (Vegetation) [39], [41]. Training samples were taken based on visible pixels, geometry, Google earth imagery (for Verification) and our best opinion. All this classification work was done by ESRI's ArcMap 10.7.

Accuracy Assessment

The accuracy assessment was carried out on the classified thematic maps using the confusion matrix method. There is no ground trothing involved due to lack of resources. This is normally used for the accuracy assessment of the remote sensing data. The accuracy of classified images was also assessed using the Kappa coefficient (42).

Land Surface Temperature from Satellite data

To evaluate LST by satellite data, thermal emissions transmitted from the surface to the satellite were used [43]. To better understand the effect of urban temperature with respect to the change in LULC hotter month of the region were selected such as: March and April. The method used for LST retrieval is a single-window algorithm from existing studies [44], [45] The

Table 1: Specification of all satellite images used in present study

Year	Image ID	Path Row	Date of Acquisition	Resolution	Location
1990	LT51520411990112RSA00	152/41	22-04-1990	30	Sukkur/Larkana
1990	LT51510431990073RSA00	151/43	14-03-1990	30	Hyderabad (tile 1)
1990	LT51510421990073RSA00	151/42	14-03-1990	30	Hyderabad (tile 2)
2020	LC81520412020067LGN00	152/41	07-03-2020	30	Sukkur/Larkana
2020	LC81520422020067LGN00	152/42	07-03-2020	30	Hyderabad

equations used for the calculation of LST are given below.

$$\text{Eq 3}$$

$$BT = \frac{\text{K}_2}{\ln\left(\frac{\text{K}_1}{\text{L}_\lambda} + 1\right)} \quad \text{Eq 4}$$

$$LST = BT - 273.15 \quad \text{Eq 5}$$

$$\frac{NDVI - NDV\text{S}_{soil}}{2} \quad \text{Eq 6}$$

$$\varepsilon = 0.004 \times PV + 0.986 \quad \text{Eq 7}$$

Results & Discussion

The LULC maps were created after the preprocessing and maximum likelihood classification as shown in figure 3. Google Earth imagery was used for the ground-truthing of the data as presented in Tables 2, 3, and 4. It can be seen that the overall accuracy of Hyderabad, Larkana and Sukkur in 1990 was 96.69%, 87.14% and 87.30% respectively. And in 2020, the overall accuracy for these cities was observed as 89.06%, 88.57% and 92.75% respectively.

These results indicate that the overall classification accuracies for the classified LULC maps were better than 70% for both of the years. Which represents strong to perfect agreement for the accuracy of image classification [46]. The kappa statistics for the classified LULC maps of Larkana, Sukkur and Hyderabad for the years 1990 were found as 83.35%, 83.89%, and 96.06%, respectively. For the year 2020 the kappa statistics were found as 84.69%, 90.44% and 86.06%.

LULC changes

The LULC changes in the study area for the last three decades can be seen in figure 3a and b. While table 5 and figure 4 summarizes the LULC changes for each type of land for both years. Urban area in Hyderabad is expanded from 82 Km^2 to 97 Km^2 from 1990 to 2020. Followed by Sukkur from 18 Km^2 in 1990 to 25.7 Km^2 uran expansion occurred in 2020. The least amount of urban expansion occurred in Larkana from 33 Km^2 in 1990 to 34.6 Km^2 in 2020. Collectively, it is observed that there is a clear and rapid urban development in all three cities. Rapid urban development in other areas can cause a lot of loss to the natural green spaces. As we can see that in Bangkok from 1994 to 2012 in nearly 2 decades, 14% vegetation loss is recorded and urban area is increased by 10% [47]. Another study conducted in Lagos, Nigeria represents the similar expressions of urban expansion [46].

In this study only Hyderabad showed the loss of green spaces from 308 Km^2 to 239.5 Km^2. Larkana on the other side showed more vegetated areas from 82.5 Km^2 in 1990 to 331.15 Km^2 in 2020. Sukkur also showed the increase of vegetation from 90.16 Km^2 in 1990 to 160.94 Km^2 in 2020. This increase in vegetation is due to the crops and fields being cultivated during the period of study.

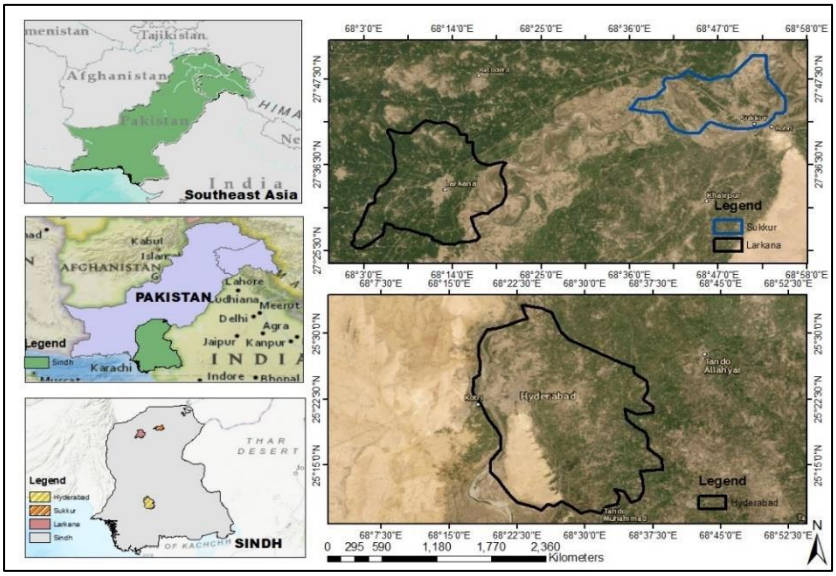

Figure 1: Representing Study area

Agriculture is also affected by the change occurred in three decades in the study area. The satellite imagery detected an increase in the agricultural areas in Hyderabad from 422 Km^2 in 1990 to 496.2 Km^2 in 2020. In Larkana, it is found as 230 Km^2 in 1990 to 56 Km^2 in 2020. In Sukkur, it is observed from 117.8 Km^2 in 1990 to 38 Km^2 in 2020. The agricultural practices and the crops shifted with time. The images were taken during the March and April months of spring. The data does not reflect any loss it just shows the detection of agriculture areas perceived in the imagery.

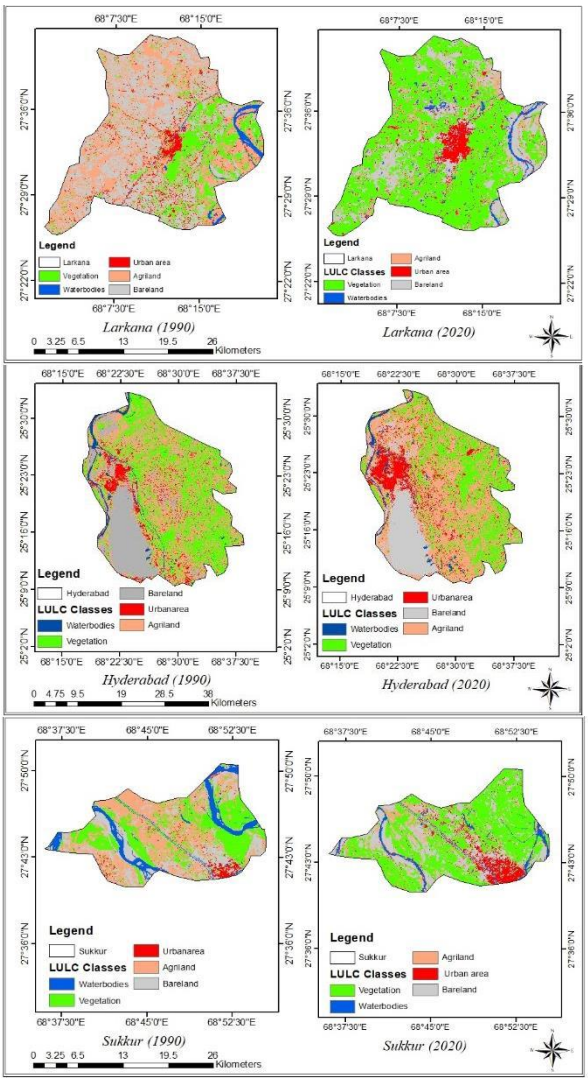

Figure 2*:* The LULC changes in three cities of Sindh for year 1990 and 2020.

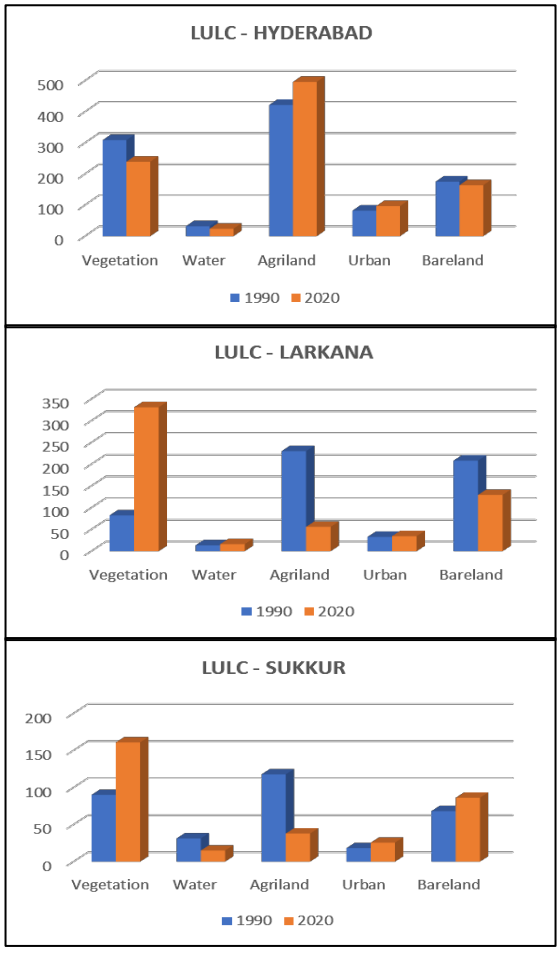

Figure 3: Pattern of Change in LULC

Overall worldwide, the major source of increased surface temperature is not only urban areas but the bare lands also. In 1990, Hyderabad had 175.5 Km^2 of bare land but in 2020 it shrunk to 164.05 Km^2 due to the utilization of some of the bare lands into urban infrastructure development. Larkana also showed a significant decrease in the bare land from 208.5 Km^2 in 1990 to 129.5 Km^2 in 2020. However, the bare land detected in Sukkur is increased from 68.21 Km^2 to 86.22 Km^2. The barren land is increased due to the conversion of the urban area. The same phenomenon is observed by [39].

The presence of inland water in the form of rivers and canals was also found in all the cities. In the imagery of Larkana, it was observed that the larger body of water or a canal going through the main city, and the least amount of water was found in Hyderabad and Sukkur. It can be seen through table 5, the water body in Sukkur is almost shrunk to nearly half of its total area i.e., from 31 to 15 Km^2. In 2020 imagery, it was observed in Larkana that many of the fields are flooded with water and the area of the water body was increased from 13.6 to 16.2 Km^2. It may be due to the cultivation of rice crops during the study period.

Variation in LST

The spatial distribution pattern of variation of the LST for both years 1990 and 2020 were created and can be seen from the figure 5a and 5b. In 1990, the image of Larkana shows the maximum temperature of 47.76°C and the minimum temperature is 25.4°C. Meanwhile, in 2020 the temperature ranges from 20.10°C to 36.99°C. The highest temperature was observed in the bare land and urbanized areas while the lowest temperature was found in water bodies and vegetative area. Same trend of Variation in LST also observed in Sukkur and Hyderabad cities, in 1990 the maximum temperature in Sukkur was observed as 43.65°C and the minimum temperature is 24.55°C. But in 2020 this range was reduced from 35.31 °C to 19.1°C. Similarly,

in Hyderabad the image of 1990 showing the maximum temperature was 35.1°C and the minimum temperature was 18°C. While in 2020 the maximum temperature is increased to 36.1°C. It is observed that in Larkana and Sukkur the 1990 imagery had more

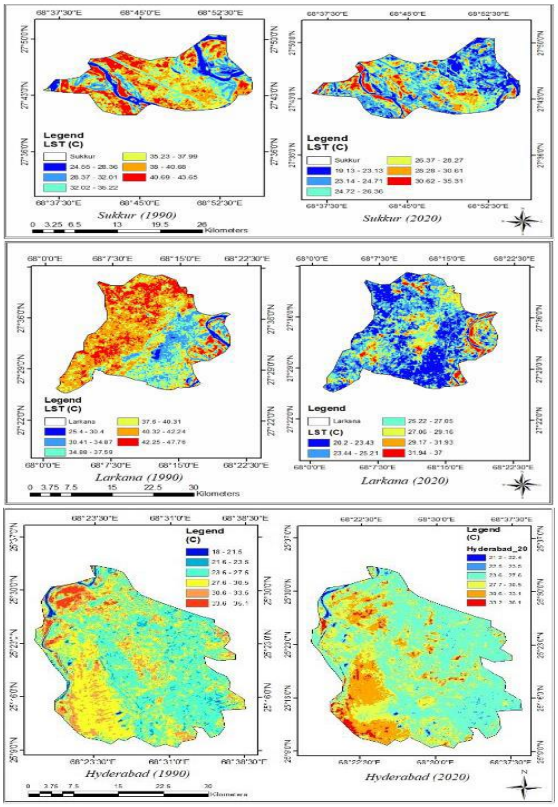

Figure 4: The Land surface temperature of three cities of Sindh.

reflectance [48], [49]. Water bodies can lower the temperature to a greater extent. Just as water, vegetation also plays important role in regulating the temperature of the urban environment. The pixels near the water bodies also showed lowering temperature than the pixels near the urban areas (Figure, 5a and 5b). In Hyderabad, comparatively a large city, the effect is visible but also due to the presence of water bodies the overall temperature is not significantly high. There is a large body of bare land at the south of Hyderabad that contains a lot of ground temperature. Hyderabad in LST imagery did not represent any significant warming effect due to urban areas. It may be because of the occurrence of large canal and large water body in Kotri barrage that controls the temperature from rising. Studies [30] also observed that occurrence of waterbodies within the urban agglomeration can reduce the LST by almost 1°C.

The mean land surface temperature was detected using ArcMap, that resulted as the decrease in mean bare land that shows significant temperature rise but in 2020's satellite imagery it can observed that only the areas that are urbanized contains high temperature. The agriculture areas that are currently bare lands also shows significantly high temperature (Figure, 5a and 5b). This can be due to the absence of vegetation cover in 1990. Most of the bare land is replaced with agriculture or urban areas in 2020, and the reduction in LST can also be observed in the same areas. The change in the land cover affects the heat absorbance and other environmental factors i.e. transpiration and temperature in all three cities i.e., in Larkana the temperature was reduced from 39.3°C to 25.46°C. In

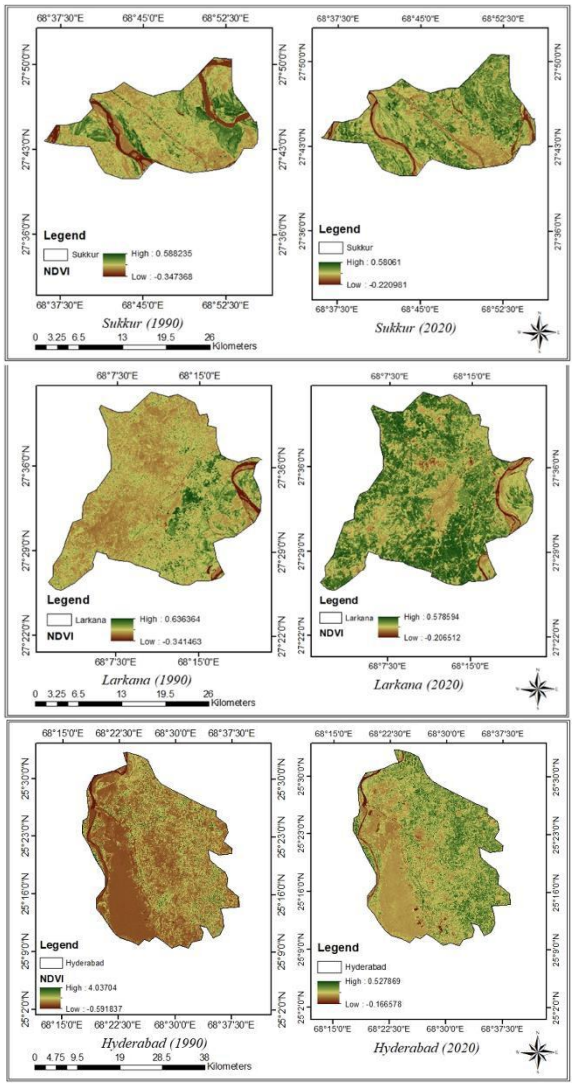

Figure 6: The NDVI map of three cities of Sindh.

Sukkur city the temperature was decreased from 36.03°C to 25.64°C. This reduction in temperature is due to the agriculture and vegetation growth in the

study area (Figure, 6), which confirms the fact that vegetation can play significant role in balancing urban heat island effect. However, in Hyderabad city the difference in mean temperature is quite minimal i.e., from 30.07°C to 27.63°C because the vegetation cover is reduced in the study area in 2020 along with that water body also played their role in maintaining urban temperature.

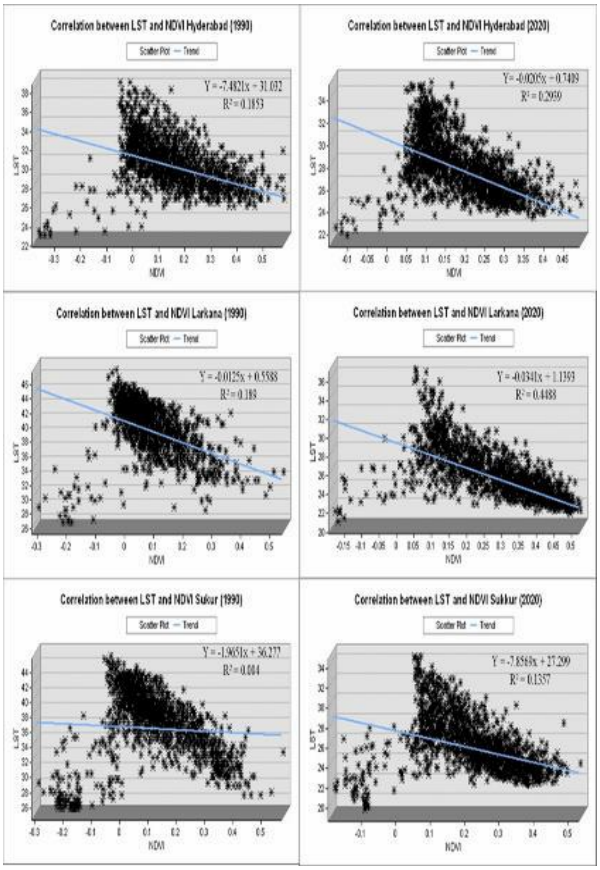

Figure 5: The Correlation between LST and NDVI

Correlation between indices and LST

To identify the connection between LULC, LST and UHI, scatter plots were created. Along with that correlation coefficient was calculated between LST and the indices. To find out the relationship between vegetation and surface heat. The graphs (figure 7) showing the trendline where there is an increase in NDVI value the LST value decreases in every city. It represents the negative correlation between the vegetation and the surface temperature [50]. Similar trend is observed in all of the other images of the cities. Hence, various researchers have suggested in their studies that vegetation cover could be very helpful in maintaining the urban climate and to improve the quality of air [43], [51]. Similarly, figure 8 establishes a strong positive trend of LST and NDBI with R^2 value ranging from 0.48 to 0.69, indicating that the land occupied by urban area and baren land can strengthen

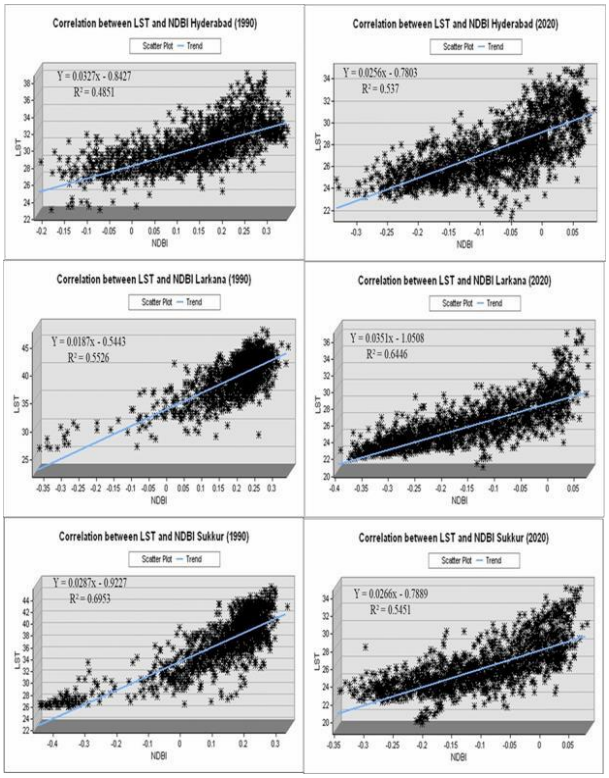

Figure 8: The Correlation between LST and NDBI

the effect of urban heat island in the study area due to its direct relation with LST, which is also evident from other studies [52], [53]. Mostly, the high heat absorbing areas in the proposed study were consisted of the barren land and urban settlements in all of the three cities. In such areas warming effect is much higher due to the biophysical properties of the surface and other climatic factors [54]. Hence, better and effective planning is required for any new urban settlement that can help to manage the UHI and LST [55].

Conclusion

The study of urban heat island is getting more attraction these days among remote sensing research workers. With the awareness of global warming and urbanization, and with the rapid development in satellite technologies. This study reveals that changes in LULC has greater impact on temperature and development of urban heat island. Conversion of green spaces to urban or bare land indicates rise in temperature and vice versa. The study reveas that the vegetation has substantially increased in Larkana and Sukkur cities. This paper overall shows the significance of vegetation and water bodies in the urban areas. Thus, we have concluded that the urban space development needs more attention by the city planners.

Conflict of Interest

There are no conflicts of interests in publishing this manuscript.

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